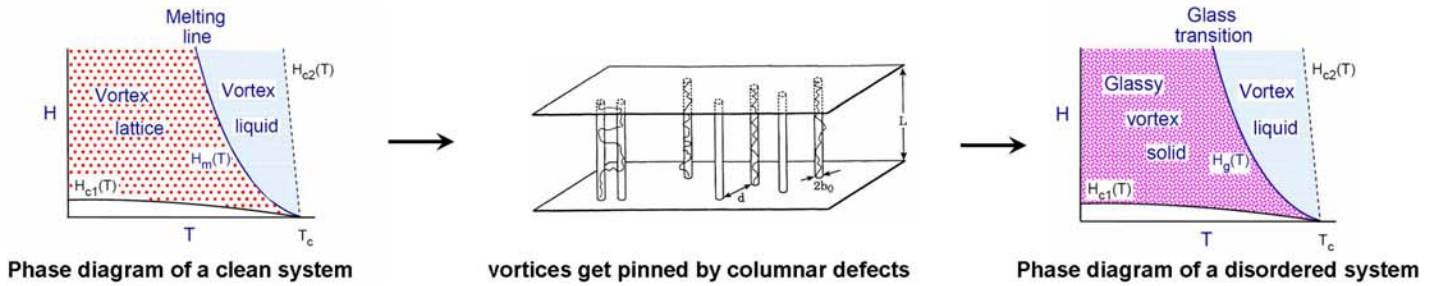


Competing Localization of Vortices

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Vortex lines can be mapped onto world lines of the 2D Bosons

$$\exp -\frac{1}{T} \int dz \frac{\varepsilon_l}{2} \left(\frac{dr}{dz} \right)^2$$

Statistical mechanics of 3D vortex system

$$\text{Vortex linear tension } \varepsilon_l \leftrightarrow \text{Boson mass } m$$

$$z \rightarrow -it \quad T \leftrightarrow \hbar$$

$$\exp \frac{i}{\hbar} \int dt \frac{m}{2} \left(\frac{dr}{dt} \right)^2$$

Quantum mechanics of 2D Bosons

Formation of the Bose glass phase is equivalent to localization of 2D quantum particles in the random field of point defects. Melting into a liquid phase corresponds to delocalization effect

Dirty bosons: effect of disorder.
Depletion of superfluid density

intermediate state: superfluid and localized components present simultaneously

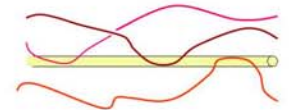
Will *arbitrarily weak* disorder localize the part of the condensate?

$$\frac{\delta n_s}{n_s} = -\frac{\hbar}{\tau(\mu)\mu}$$

Can be viewed as pinning of some fraction of vortices in the vortex liquid

A.V. Lopatin and V.M. Vinokur,
PRL 88, 235503 (2002)

Pinning by one strong defect: one vortex is always pinned.
Many vortices: Vortices wander freely and screen each other out from columnar defect. Thus, if the defect potential is not sufficiently strong, vortices may *depin*.

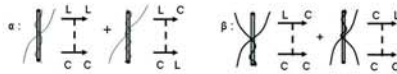


Disorder and Bose condensate

$$\hat{H} = \int d^2r \psi^\dagger \left[p^2/2m - \mu + U(r) \right] \psi + \int d^2r_1 d^2r_2 \psi^\dagger(r_1) \psi(r_1) V(r_{12}) \psi^\dagger(r_2) \psi(r_2)$$

Effective model that describes occupation of the localized states:

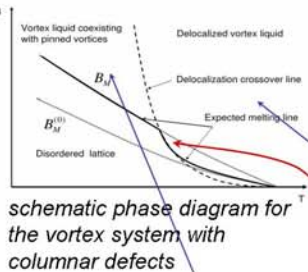
$$\hat{H}_{\text{eff}} = \hat{b}_1^\dagger (E_1 + \alpha - \mu) \hat{b}_1 + \beta (\hat{b}_1^\dagger + \hat{b}_1)$$



occupation number $n = \hat{b}_1^\dagger \hat{b}_1$
Crossover from occupied to non-occupied state of defect occurs at $n=1/2$:

$$B = \frac{\Phi_0 \kappa^4 T^2}{(\Phi_0 / 4\pi)^4 \ln(\lambda / \ell_\perp)} \exp\left(-\frac{T}{T^*}\right)$$

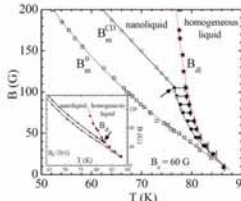
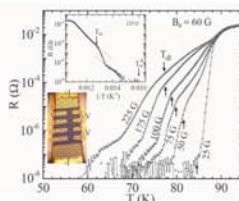
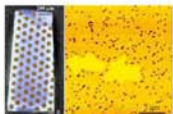
Above the transition correlations in z direction disappear: liquid of vortex segments



Below delocalization line correlations restore: vortex line liquid

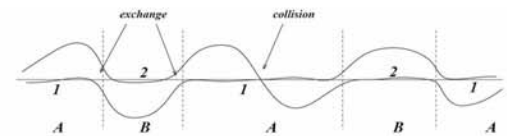
Delocalization-induced melting of the vortex lattice

Experiment: E. Zeldov group at Weizmann Institute



Exactly Solvable Model:

N Flexible Lines Near the Defect

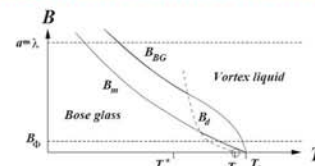


two particles binding alternately to a single columnar defect with exchange & rare collisions

Grand canonical partition function:

$$G(z) = \frac{G_A + G_B + 2vG_A G_B}{1 - v^2 G_A G_B} \Big|_z = \frac{2G_A(z)}{1 - vG_A(z)} \quad v \equiv \exp(-E_{\text{ex}}/T)$$

Transition occurs when singularities of G_A and $1-vG_A$ coincide



Generalization to N lines

Future directions

Is the "depinning" liquid really free?

Future plan:

weak localization of vortex liquids

J. Kierfeld and V. M. Vinokur, Phys. Rev. Lett., 94 77005 (2005)